# DInSAR Measurement of Soil Moisture

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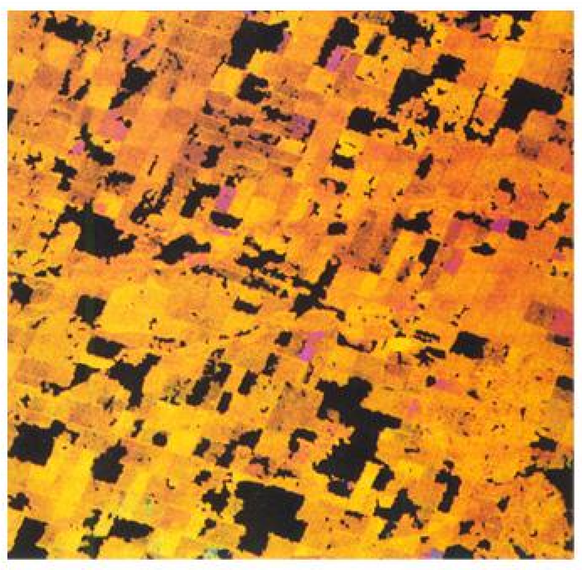
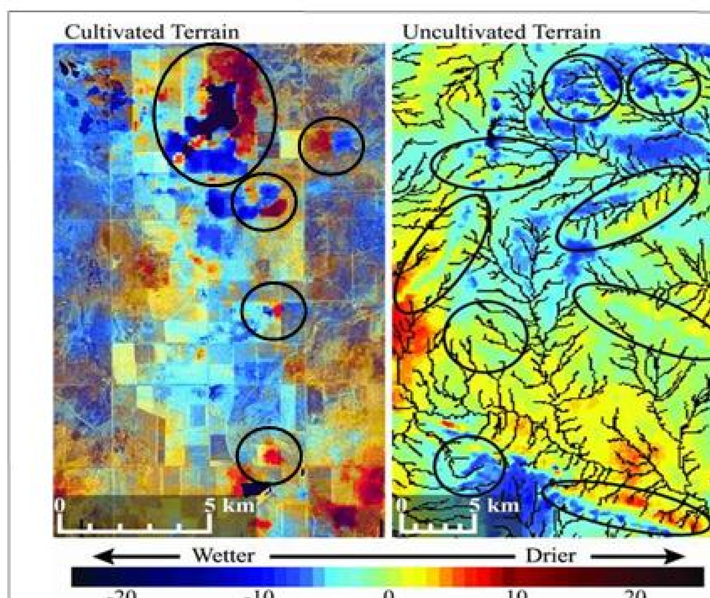
## Overview

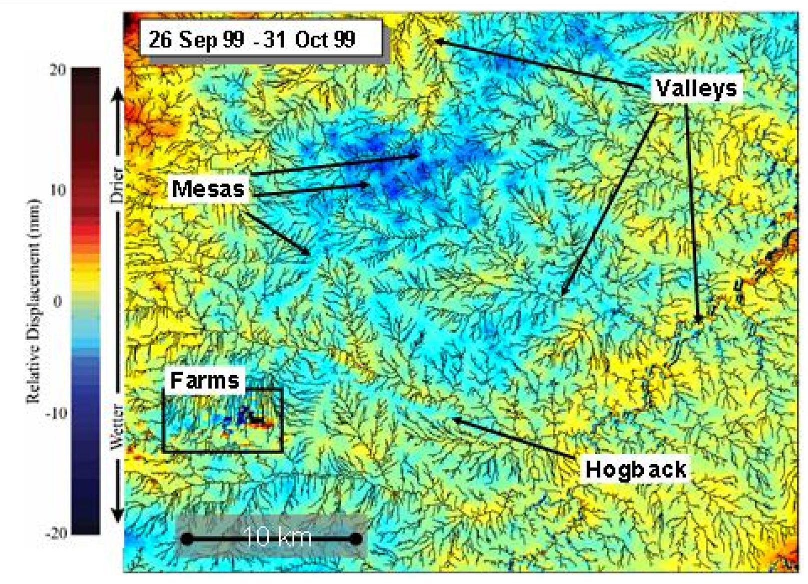
This poster describes some of the substantial evidence from theory and observations that suggests that InSAR phase contains a soil moisture signal which may be exploitable for operational measurements using existing technology, on the spatial scale of meters and moisture resolution of a few percent by volume.

## Prior literature demonstrates qualitatively that phase is sensitive to soil moisture at a detectable level

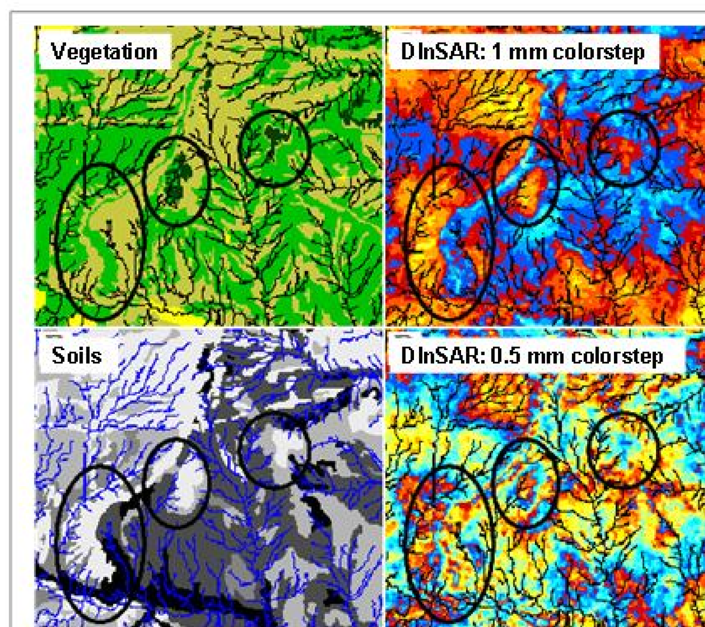


Detection of a soil moisture signal was first conclusively demonstrated by Gabriel et al. (1989), in the first interferograms (made with L-band SeaSat) by confirming that phase changes associated with linear farm field boundaries were caused by irrigation in 50 out of 52 cases. They theorized that expansive clays caused surface elevation changes that affected phase, but never verified this through soils analysis.




In a one year time-series of ERS-2 interferograms, Nolan et al. (2003) found phase variations on the order of millimeters in both farm fields and uncultivated terrain, in locations without expansive clays, and theorized that they could be explained by a change in penetration depth due to a permittivity change caused by soil moisture variations. Their field data and observations ruled out competing explanations (atmosphere, topographic residuals, vegetative growth, etc) and theoretical analysis suggested phase signals of this magnitude should be present.

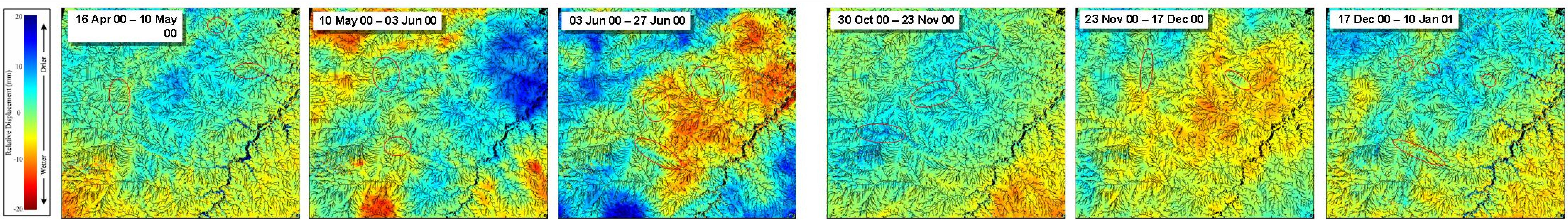



Vegetation and soils maps at left were from airphotos, not SAR.

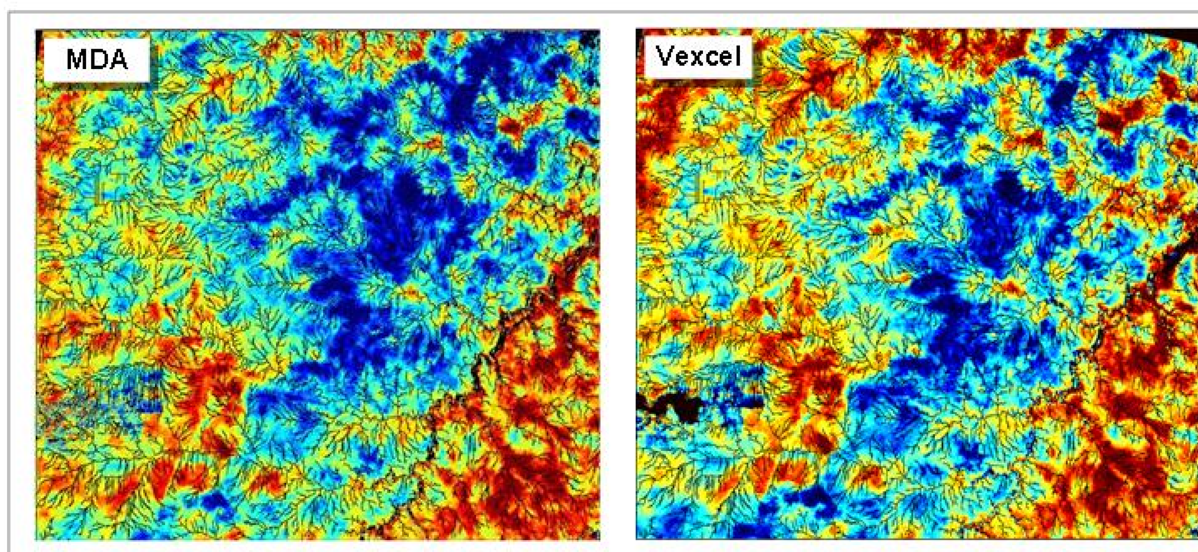
Same SAR signal data shown with different colormaps to assess the limits of phase resolution.

Nolan et al (2003) demonstrated that ground-based phase signals as small as 0.5 mm were detectable using conventional InSAR provided a DEM of sufficient accuracy was used.

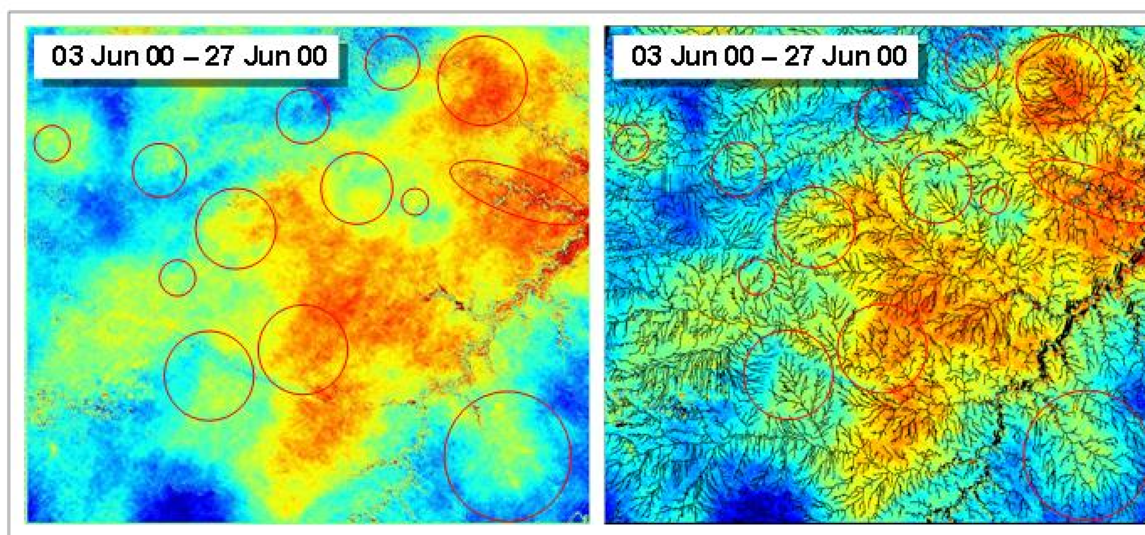
## Recent Satellite studies confirm and extend prior observations of signals that appear to be caused by soil moisture variations



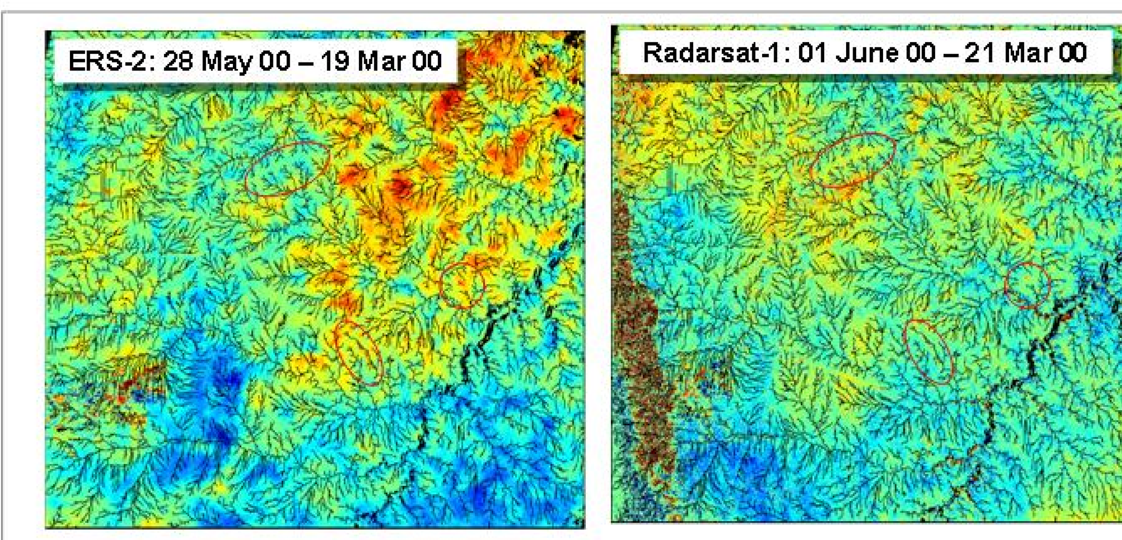

**Subtle variations in phase are closely correlated to topography, but the specifics vary month-to-month, as we would expect for soil moisture variations.** If these phase variations were due to topographic residuals from processing, each pair would show the same topographic-relationship scaled by baseline, which is clearly not the case here. Our study area is in a remote region of southern Colorado used for military ground maneuvers (Pinon Canyon Maneuver Site); these scenes are roughly 40 km across. The sparsely vegetated landscape is dominated by mesas and hogbacks, where we expect moisture retention properties to vary by watershed. Here we use a stream channel network (black lines) to indicate topography – the higher ground of ridges are found where the streams start. Note how in each of the Radarsat interferograms above there are many spatial variations that relate closely to the shape of the land, but the relief is too low for variations in atmospheric thickness or density to create the subtle signals on the 100 m scale seen here (see examples in red ellipses). Shown here are 3 pairs from summer and 3 pairs from winter; note how the variations are higher in summer, as might be expected for a soil moisture source.




**Our results are independent of the SAR processor used.** Here we show the same interferometric pair of ERS-2 data processed with software from Vexcel and MDA, which show nearly identical results despite using different DEMs (though of similar quality) and processing tricks. The TRE processor shows the same result as well. This eliminates any chance of blunders in our original work and suggests that any processor can yield similar results.

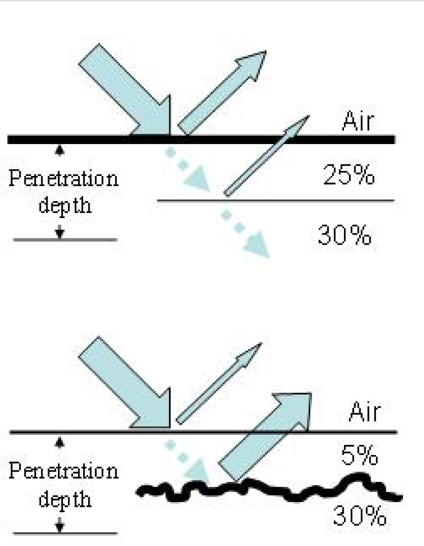



**Without overlaying a stream channel network, many subtle and large signals might otherwise appear to be of atmospheric origin.** Our current research is attempting to distinguish these signals quantitatively using a variant of the PS technique, but qualitatively this can be assessed with some information on topography. The stream channel network is the simplest approach we have found for comparing phase signals to topography.



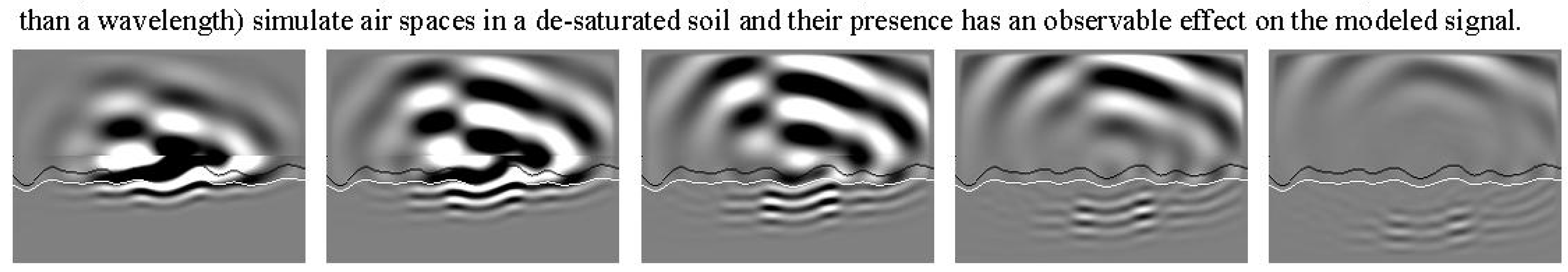

**ERS and Radarsat both reveal similar spatial and temporal patterns.** The pair above is the closest temporal overlap in our time-series of ERS and Radarsat, and show similar spatial trends. We suspect the main reasons for the differences are 1) the difference in acquisition dates and 2) the difference in polarization. Our modeling indicates that the differing polarizations used *should* yield slightly different results.

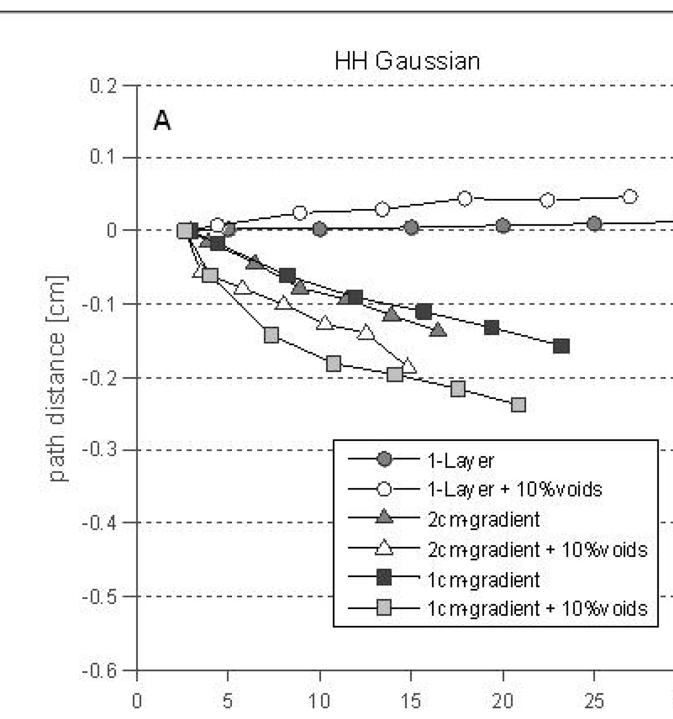
## New modeling establishes background theory and provides quantitative assessment




Modeling has shown that the amount of phase change depends not only on the depth of subsurface contrasts, but also on their relative reflectivities. For example, if, as soils dry, a subsurface interface remains wetter or becomes (dielecrically) rougher, phase changes of tens of degrees can be explained as this subsurface signal dominates the net phase signal received at the satellite.

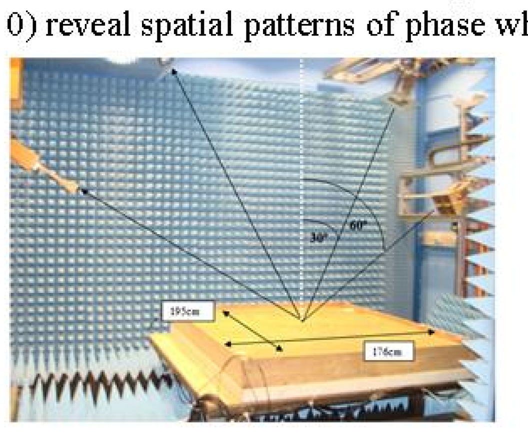
**It's all about superposition.** Below are a few screenshots of the 2D FDTD model we recently developed, which can simulate the interactions of SAR microwaves with nearly any soil structure. Here a two-layer case is used to demonstrate superposition of reflected waves. This modeling indicates that when soils with no vertical gradients change in soil moisture (eg., from all wet to all dry) the change in phase is negligible, because the dominant phase component is always the air-soil interface. As illustrated at left, when vertical gradients exist, these subsurface layers can overwhelm the surface reflection and dominate the phase signal. The quantitative result is shown at right, for no gradient (1 layer) and linear gradient from 3% at surface to the value indicated on the x-axis (over a 1 or 2 cm distance), and are on the same order (millimeters) as satellite and lab observations. Voids (much smaller than a wavelength) simulate air spaces in a de-saturated soil and their presence has an observable effect on the modeled signal.

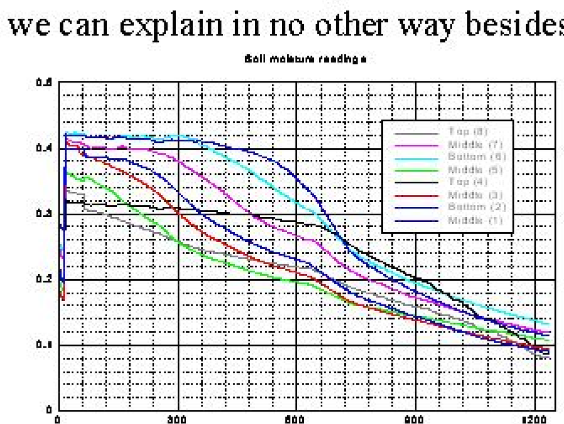


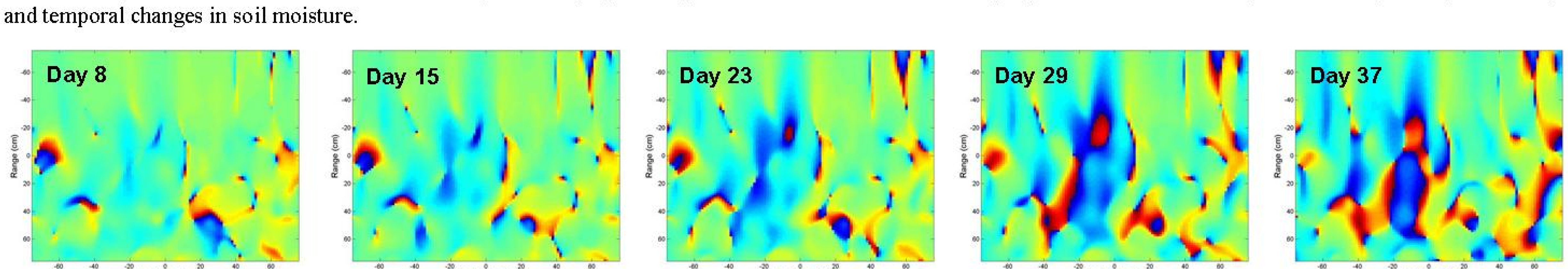



## Laboratory measurements support numerical modeling results and conclusively demonstrate a soil moisture source for phase variations

Using a SAR within an anechoic chamber, we observed temporal and spatial changes in phase as a roughly 2m x 2m x 0.2 m soil volume dried out over the span of seven weeks. Surface elevation variations were measured during the course of the experiment and found to be an order of magnitude lower than the observed phase variations. Probes continuously monitored soil moisture at various depths, verifying a change in moisture, with the surface drying earliest. The interferograms below (all compared to Day 0) reveal spatial patterns of phase which we can explain in no other way besides spatial and temporal changes in soil moisture.






## Conclusions

Prior literature, FDTD modelling, satellite measurements, and laboratory modeling all suggest that standard InSAR phase is sensitive to variations in soil moisture, through a sub-surface change in path length. This signal is strong enough to be measured using existing SAR satellites, anywhere that traditional InSAR techniques work (eg., excluding problems of shadowing/layover). We believe enough support for this technique now exists to justify a significant effort by the remote sensing community to validate and expand on our research for the purpose of developing an operational system for soil moisture measurement.

**References:** Gabriel, A.K., Goldstein, R., and Zebker, H.,1989. Mapping small elevation changes over large areas: Differential radar interferometry. J Geophys. Res, 94, 9183-9191 ● Matt Nolan, Rob Fatland, and Larry Hinzman, 2003. DInSAR measurements of soil moisture. IEE TGRS, 41(12), 2802-2813

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